TITLE: Photoluminescence Study of Electronic Structure of InAs Quantum Dots Grown on GaAs Vicinal Surfaces

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Photoluminescence study of electronic structure of InAs quantum dots grown on GaAs vicinal surfaces

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Abstract. Photoluminescence (PL) study results of InAs/GaAs quantum dot (QD) arrays on vicinal GaAs(100) substrates at InAs thickness fixed to 1.8 monolayers are reported. It is shown that at $T =$ 4 K PL peaks from QDs are blue-shifted and their full width at half maxima decreases as substrate misorientation angle towards various directions raises from 0 to 7 degrees. The intensity of this emission band decreases at the temperature rise and at $T > 80$ K two bands with longer wavelength are clearly observed in PL spectra too. The excitation intensity and temperature dependences of PL spectra at 4–300 K indicate that observed PL spectra structure can be explained by the emission from both lowest and excited levels of QDs with average size 8–9 nm.

Introduction

One of the most promising ways to fabricate nanostructures is the direct QDs formation due to self-organization effects during molecular beam epitaxial (MBE) growth in mismatched heteroepitaxial systems. Spontaneous formation of the arrays of three dimensional islands was observed in various semiconductor systems, in particular InAs/GaAs (see e.g. review [1] and references therein). The properties of InAs/GaAs QDs were studied by various methods. However, the main attention was paid to the study of nanoobjects obtained by conventional MBE on singular GaAs(100) surfaces. Recent study (see e.g. [2, 3]) shows that the growth on vicinal substrates and/or the use of submonolayer migration enhanced epitaxy (SMEE) technique for QDs fabrication lead to the formation of QDs with lower deviation from mean size and to the decreasing of threshold current density at laser generation. The electronic structure of such QDs system is studied in particular *via* PL spectra. These spectra are complex enough and it is the subject of discussion so far [4, 5]. The aim of this work is the PL study of InAs/GaAs QD arrays obtained by SMEE on the GaAs(100) misoriented substrates in dependence on the excitation intensity and temperature.

1 Experiment and results

The structures consist of the InAs QDs confined from both sides with wide-gap GaAs and $Al_{0.25}Ga_{0.75}As$/GaAs superlattices (5 pairs, 2 nm/2 nm each) on GaAs (100) semi-insulating substrates misoriented towards [001], [010], [011], [00$\bar{1}$] and [0$\bar{1}$1] direction by 0° (singular substrates) — 7° are used. The samples growth has been written in detail in [2].

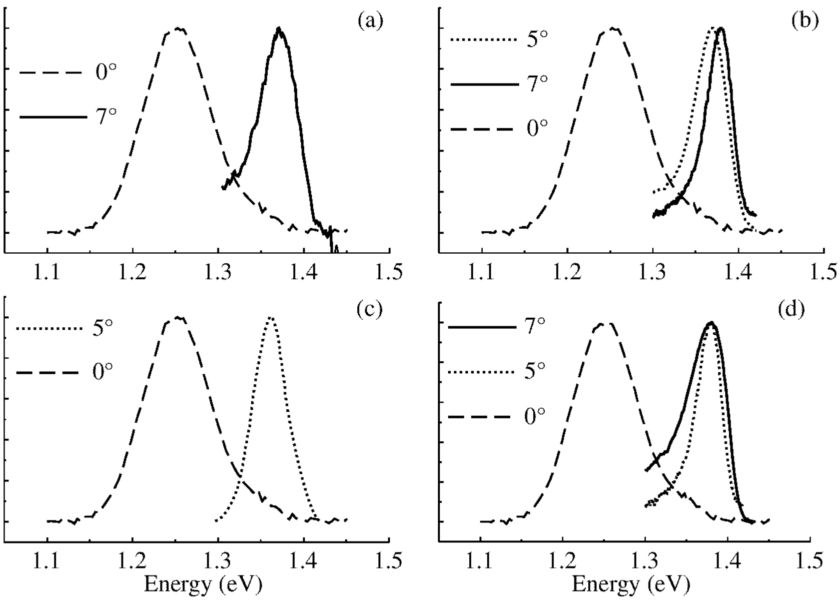

Fig. 1. PL spectra of InAs/GaAs sample with the singular surface and surface misoriented towards various directions. (a) [00$\bar{1}$], (b) [010], (c) [011], (d) [0$\bar{1}$1]) at $T = 4$ K.

The QDs emission band with the intensity maximum near 1.25 eV is observed in typical PL spectra of samples with singular surfaces at $T = 4$ K. Besides this broad band the lines of GaAs exciton and impurity emission with maxima near 1.5 eV are observed.

Monotonous shift of intensity maximum from 1.25 eV to 1.38 eV and decrease of emission band full width at half maxima (FWHM) have been observed as misorientation angle increases from 0° to 7° towards [001] direction. Strong decrease of FWHM in dependence of the misorientation angle is attributed to the size distribution narrowing while the average lateral size of QDs decreases [2]. The angle dependence of PL spectra is qualitatively the same for another directions too but with the higher width of QDs emission band (Fig. 1).

Besides the dominating emission band (1.38 eV) the longwave tail is observed in PL spectra at $T < 80$ K. Up to five weak maxima were observed in this tail for some samples with maximum misorientation angle. The intensity of shortwave band (1.38 eV) drastically decreases at $4\text{ K} < T < 80$ K and the longwave bands dominate in PL spectra at $T > 80$ K. We have found from temperature dependence of shortwave band intensity that activation energy for this band is nearly 5 meV.

The QDs emission complex curve can be fitted by a sum of Gaussian contours in the whole temperature range 80–300 K. The most longwave band is broader than shortwave band. The temperature shift of longwave band maximum at $T > 80$ K is few times higher than temperature shift of GaAs bandgap. The temperature shift of most shortwave band maximum (1.38 eV) observed at temperatures 4–80 K is higher than temperature shift of GaAs bandgap too. The relative intensity of shortwave PL bands goes up with the increase of excitation intensity at $T > 80$ K (Fig. 2).

While further excitation intensity increases these QDs emission bands also saturate and in this case GaAs substrate emission dominates in PL spectra. Excitation spectra of QDs

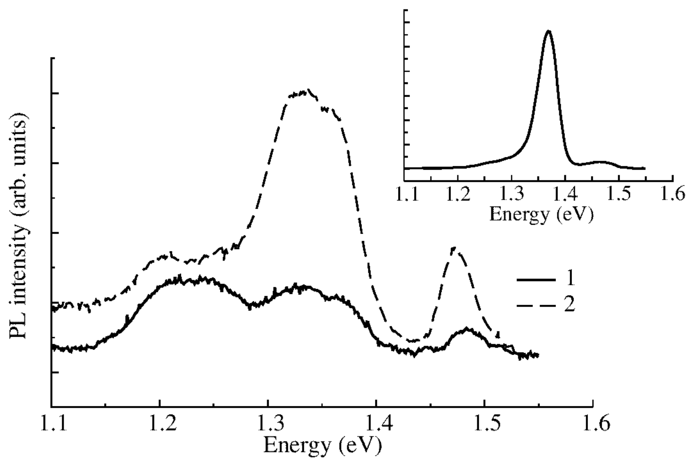

Fig. 2. Dependence of PL spectra of InAs/GaAs sample (7°, [001]) on excitation intensity (1—100 mW, 2—400 mW) at $T = 170$ K. Insert — this sample PL spectrum at $T = 10$ K and excitation intensity 100 mW.

emission bands has been measured too and energy relaxation with LO-phonons emission has been observed.

2 Discussion

We believe that results obtained confirm our explanation of the shape of PL spectra of QDs on vicinal surfaces by the emission from both lowest and excited levels of QDs [5]. It has been shown in models [6–8] that at non-resonant excitation excited levels in the QDs can be populated even in the case of empty lower levels. This situation may appear if recombination rate of excited states in the QD is higher than the rate of interlevel transitions.

We suppose that the most shortwave PL band observed at low temperatures is the emission of excited state of the QDs. This band intensity decreasing observed as temperature rises may be explained by faster thermal depopulation of excited levels. PL band maxima positions are fitted by the theoretical calculations [9] if QDs lateral size is near 8–9 nm. The excitation intensity dependence of PL spectra at $T > 80$ K is then explained by saturation of lower levels.

Taking into account also the spectral dispersion of QDs levels energy due to QDs size distribution the greater red shift of QDs emission band maxima observed at PL spectra depending on the temperature may be the evidence of thermal redistribution in the nonuniformly broadened system of QDs levels.

3 Conclusions

To conclude, we have studied PL spectra of InAs QDs grown by SMEE method on the vicinal GaAs(100) substrates with inclination angles towards various directions up to 7°. It is shown that PL peaks become narrower and are shifted towards shorter wavelengths with the rise of misorientation angle at fixed amount of InAs deposited. The excitation intensity and temperature dependences of PL spectra at 4–300 K indicate that the structure observed can be explained by the emission from both lowest and excited levels of QDs with average size 8–9 nm.

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